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BOSTON UNIVESITY
COLLEGE OF ENGINEERING
FINAL REPORT

**Brockettfest:
A Conference on Mathmematical Control Theory**

ARO Grant No. DAAG55-98-1-0391

Report prepared by

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September, 1999

Abstract

This report summarizes a scientific meeting/conference which was supported in part by a grant from the Army Research Office. The conference was held in Cambridge, MA on October 23,24, 1998. The occasion marked the sixtieth birthday of Roger W. Brockett, and more than one hundred leading control theorists traveled to Boston to attend two days of lectures and a formal banquet. No formal conference record was published, but a volume of technical articles discussing current research related to Brockett's work was published. The book entitled *Mathematical Control Theory* is available from Springer-Verlag as indicated in the report.

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Brockettfest: A Conference on Mathematical Control theory

Grant DAAG55-98-1-0391

FINAL REPORT

Abstract

This report summarizes a scientific meeting/conference which was supported in part by a grant from the Army Research Office. The conference was held in Cambridge, MA on October 23,24, 1998. The occasion marked the sixtieth birthday of Roger W. Brockett, and more than one hundred leading control theorists traveled to Boston to attend two days of lectures and a formal banquet.

1 Perspectives in Control: A conference honoring the work of Roger W. Brockett

As quoted in the book *The Experts Speak* by C. Cerf and V. Navasky, James Ussher, Archbishop of Armagh in the seventeenth century, propounded that "The world was created on 22d October, 4004 B.C., at 6 o'clock in the evening." An event of note for our own professional community occurred on the same date nearly six millennia later when in 1938, our colleague Roger W. Brockett was born in Seville, Ohio. In honor of his 60-th birthday, a two-day symposium was held in Boston and Cambridge, Massachusetts, on October 23 and 24. The symposium received financial support of the U.S. Army Research Office and the National Science Foundation.

Among its many high points, the symposium started off with a keynote address by Karl Johan Åström from the Lund Institute of Technology in Sweden, entitled "Automatic Control: A Perspective". The lecture was perfect for the occasion. Karl sketched the development of the field from the early days of the industrial revolution and the pre- and postwar era, via the stormy theoretical developments of the sixties, to today's high tech applications. He emphasized that control is in an essential way an enabling field, and he expressed this very aptly by stating that control is a field with a soul, but without a body. Particularly refreshing in this keynote address was the tone of contagious optimism concerning the great industrial relevance of the field of control combination with the computer technology.

The symposium featured about 40 speakers, the majority co-workers (mainly former Ph.D. students and post-docs) of Roger Brockett. It is no accident, of course, that the development of nonlinear control theory and Roger Brockett's career coincided, and all the speakers emphasized the inspiration which his work has provided for their own research. The talks ranged from nonlinear controllability and feedback linearization to quantum systems. Many speakers touched upon the various subtle aspects of the deceptively simple looking non-linear system:

$$\begin{aligned}\dot{x}_1 &= u_1 \\ \dot{x}_2 &= u_2 \\ \dot{x}_3 &= x_1 u_2 - x_2 u_1,\end{aligned}$$

the Brockett integrator. That this would be a featured part of so many talks was foreseen by a number of enterprising graduate students who distributed t-shirts displaying these equations.

The symposium ended with a formal dinner. Formal is a relative notion. For the case at hand, it emphasized the elegant surroundings of the Harvard faculty club and the suggestion to honor the occasion by using fork and knife and not throw the food at the other guests. Sanjoy Mitter from MIT gave a light-hearted after-dinner *Laudatio* at the banquet.

A Festschrift was published for the occasion, *Mathematical Control Theory*, edited by John Baillieul and Jan C. Willems (Springer Verlag, 1998, ISBN 0-387-98317-1). It contains Roger Brockett's vitae, a list of his publications and his Ph.D. students and postdocs, and nine extensive articles about various aspects of the field to which Roger Brockett has made seminal contributions.

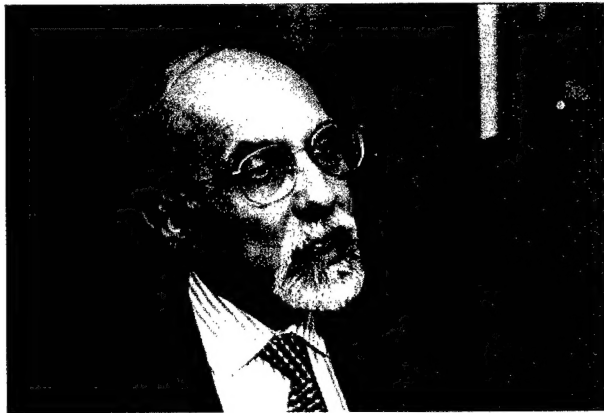
Brockettfest: Conference Photos, October 23,24, 1998



Karl Åstrøm and Louise Baxter and Roger Brockett enjoy a light moment.



Carolann Brockett, Bill Levine, and Roberto Canales discuss changes that have occurred in the field over the past quarter century.



Sanjoy Mitter reflects on work he has done with Brockett.



Karl Åstrøm gives an optimistic assessment of the future.



Roger Brockett, Venkatesh ("Venky") Narayanamurti and David Dobkin discuss engineering principles in computer science

3 Conference Summary

The *Brockettfest* Conference was a great success, bringing together a large number of researchers for a focused two-day discussion of thirty year's research on modern mathematical control theory (and also very interesting applications in mechanics and computer science). The Conference was jointly sponsored and supported by the U.S. Army Research Office (Dr. Linda Bushnell), the National Science Foundation (Dr. Radhakisan S. Baheti), Harvard University, and Boston University. The meeting stretched over a two-day period—October 23,24, 1998 with technical sessions split between Boston University (Friday morning) and Harvard University. The banquet on Saturday, October 24, was yet an additional occasion for professional (as well as informal) interaction, and a number of speakers (both scheduled and *impromptu*) spoke about Brockett's work and its significance. The banquet was held in the very pleasant second floor suite of the Harvard Faculty Club. Summary statistics regarding the Conference are provided in the following table:

Brockettfest Summary Statistics	
Total attendance	130
Total number receiving partial support of travel	44
Total scheduled technical lectures	44
Sponsorship	
Agency funds were used to support participant expenses including round-trip airfare, meals, and lodging.	
Army Research Office	\$30,000
Nat'l Science Found.	7,000

A summary of travel reimbursements to participants is given on the following page. *Additional participant support was provided through directly paid meal and meeting costs at the Conference, but these charges were not itemized on an individual participant basis.* The Conference speakers are listed together with their affiliations on the pages after that. The meeting had a strong international flavor with 19 of the speakers (slightly less than half) being from foreign institutions.

The Selection of the Program

The technical program was set by a small Program Committee consisting of John Baillieul (Boston University), Jan C. Willems (University of Groningen), Pierre Dupont (Boston University), and Sanjoy K. Mitter (MIT). All the plenary speakers were invited, but among the other speakers there was about an even split between invited and contributed talks. A sample letter of invitation is appended to this report.

Brockettfest: Travel Reimbursements Paid from Federal Grant Sources					
Title	First Name	Last name	Amount Awarded	REMARKS	
Prof.	Karl	Astrom	\$ 3,054.86	Keynote speaker	
Prof.	D.	Aeyels	\$ 650.00		
Prof.	A.	Astolfi	\$ 449.40		
Dr.	Walter	Baker	\$ 300.00		
Prof.	John S.	Baras	\$ 763.69		
Prof.	Anthony M.	Bloch	\$ 725.31		
Prof.	Peter	Caines	\$ 53.00		
DR.	Roberto	Canales	\$ 624.00		
Prof.	Greg	Chirikjian	\$ 410.77		
Dr.	Jim	Clark	\$ 130.00		
Dr.	Martin	Clyde	\$ 1,150.00		
Prof.	Peter E.	Crouch	\$ 1,000.00		
Dr.	Jeroen	Dehaene	\$ 561.20		
Prof.	David P.	Dobkin	\$ 355.50		
Prof.	Leonid	Faybusovich	\$ 500.00		
Prof.	P.A.	Fuhrmann	\$ 2,100.00		
Prof.	Katsuhisa	Furuta	\$ 934.67		
Prof.	Jacob	Hammer	\$ 300.00		
Dr.	Bernard	Hanzon	\$ 650.00		
Prof.	Uwe	Helmke	\$ 650.00		
Prof.	Ron	Hirschorn	\$ 500.00		
Prof.	Joseph	Jaja	\$ 430.43		
Prof.	Hidenori	Kimura	\$ 800.00		
Prof.	Arthur J.	Krener	\$ 1,050.00		
Prof.	P.S.	Krishnaprasad	\$ 800.00		
Dr.	Francoise	LAMNABHI-LAC	\$ 509.10		
Prof.	Fatima Silva	Leite	\$ 500.00		
Prof.	Naomi	Leonard	\$ 285.00		
Prof.	Bill	Levine	\$ 500.00		
Prof.	Josip	Loncaric	\$ 520.83		
Prof.	Steve	Marcus	\$ 300.00		
Prof.	Felipe	Monroy-Perez	\$ 353.89		
Prof.	Bozena	Pasik-Duncan	\$ 395.47		
Prof.	Shanker	Sastry	\$ 465.54		
Prof.	Eduardo D.	Sontag	\$ 769.04		
Prof.	Hector J.	Sussmann	\$ 787.94		
Prof.	Roberto	Tempo	\$ 650.00		
Prof.	Duncan	Tyrone	\$ 500.00		
Prof.	Darrell	Williamson	\$ 1,000.00		
Prof.	Wing S.	Wong	\$ 2,000.00		
Prof.	Yutaka	Yamamoto	\$ 1,200.00		
Total			\$ 29,679.64		
This provides a complete list of "Brockettfest" attendees who received reimbursement or partial reimbursement from Federal grant sources.					

PERSPECTIVES IN CONTROL

A scientific conference in honor of

ROGER W. BROCKETT

Harvard University

on the occasion of his 60-th birthday

General Information

- The conference is open to anybody who wishes to attend. If you would like to attend the meeting, please preregister according to the instructions posted at <http://eng.bu.edu/Brockettfest>. Alternatively you may send e-mail to Brockettfest@math.rug.nl or JOHNB@eng.bu.edu. The information contained in your e-mail should include (i) your name, (ii) affiliation, and (iii) the number of banquet tickets you wish to order.
- The conference is held at Boston University and Harvard University. Registration will be held at the **Photonics Center of Boston University**, 8 St. Mary's Street, Boston (subway stop: Boston University Central, Green Line, Car B), starting at 8.00 a.m. on **Friday, October 23, 1998**.
- The registration fee is \$ 100. This includes coffee, tea, and a copy of the book:

MATHEMATICAL CONTROL THEORY
Dedicated to Roger Brockett on his 60-th Birthday

J. Baillieul & J.C. Willems, Eds.
Springer-Verlag, NY
ISBN 0-387-98317-1

About the book:

This book contains a collection of scientific papers written for the occasion by former co-workers of Roger W. Brockett. It is a self-contained volume which surveys three decades of mathematical control theory and which at the same time describes how the work of Roger Brockett shaped and influenced the field. While intended as a commemorative volume, the book will also provide an important reference for graduate students and researchers working in control and system theory.

- The conference will be concluded with a dinner at the Harvard Faculty Club, at 7 p.m. on **Saturday, October 24, 1998**. Tickets for the dinner are \$ 50 per person. Please mention special dietary requirements when ordering dinner tickets.
- Hotel accommodations for the meeting are described on the Web site <http://eng.bu.edu/Brockettfest>.

Program

Friday, October 23, 1998

The morning session of Friday, October 23, will take place in the Auditorium of the **Photonics Center** (Room 206) of **Boston University**, 8 St. Mary's Street, Boston (subway stop: Boston University Central, Green Line, Car B).

- 8.00 - 9.15 Arrival and registration of participants
- 9.15 - 9.30 Opening

Session 1:

Chairperson: J.C. Willems (University of Groningen)

- 9.30 - 10.30 Keynote address **Karl Johan Astrom**
Automatic Control - A Perspective
- 10.30 - 11.00 Coffee break
- 11.00 - 11.30 C.I. Byrnes (Washington University)
Geometry of Nevanlinna-Pick interpolation
- 11.30 - 12.00 P.A. Fuhrmann (Ben Gurion University)
Realization theory, the Riccati equation and spectral factorization
- 12.00 - 12.30 A.J. Krener (University of California)
Feedback linearization
- 12.30 - 13.00 C.F. Martin (Texas Tech)
Obstructions to simultaneous stabilization
- 13.00 - 15.00 Lunch

The afternoon sessions of Friday, October 23, will take place in the **Science Center of Harvard University** (subway stop: Harvard Square, Red Line). It takes about 30 minutes to transfer from BU to Harvard by subway.

Session 2: Lecture Hall A

Chairperson: (P.S. Krishnaprasad, University of Maryland)

- 15.00 – 15.25 K. Furuta (Tokyo Institute of Technology)
Generation of chaos using discontinuous sliding planes
- 15.25 – 15.50 U. Helmke (University of Würzburg)
Scaling actions and the control of numerical algorithms
- 15.50 – 16.15 F. Silva Leite (University of Coimbra)
Spline interpolation on Lie groups and spheres
- 16.15 – 16.40 D. Liberzon (Yale University)
Stability of switched systems: a Lie-algebraic condition
- 16.40 – 17.00 Tea break
- 17.00 – 17.25 F. Monroy-Perez (Universidad Autonoma-Metro-
politana)
Optimal control problem on the Heisenberg group
- 17.25 – 17.50 S.T. Smith (Lincoln Labs)
The geometry of orthogonally constrained algorithms
- 17.50 – 18.15 V. Sundarapandian (Washington University)
A necessary condition for local asymptotic stability of equilibria
- 18.15 – 18.40 D. Williamson (Australian National University)
Tensegrity systems: topology, analysis and control

Session 3: Lecture Hall D

Chairperson: (J.S. Baras, University of Maryland))

- 15.00 – 15.25 D.J. Bell (UMIST)
Junction points in singular optimal control
- 15.25 – 15.50 J.J. Clark (McGill University)
Control of active vision systems
- 15.50 – 16.15 D.P. Dobkin (Princeton University)
A novel representation for geometric objects with applications
- 16.15 – 16.40 L. Faybusovich (University of Notre Dame)
Jordan algebras, symmetric cones and interior-point methods
- 16.40 – 17.00 Tea break

- 17.00 – 17.25 J. Hammer (University of Florida)
Approximate model matching in nonlinear control
- 17.25 – 17.40 B. Hanzon (Free University Amsterdam)
Model reduction in H_2 using matrix solutions of polynomial equations
- 17.40 – 18.15 J.F. JaJa (University of Maryland)
On the design of practical parallel algorithm for combinatorial computing and image processing
- 18.15 – 18.40 P. Caines (McGill University)
On the controllability of Hamiltonian and other nonlinear systems

Saturday October 24, 1998

The sessions of Saturday, October 24, will take place in the Science Center of Harvard University

Session 4: Lecture Hall A

Chairperson: J. Baillieul (Boston University)

- 8.30 – 9.00 J.S. Baras (University of Maryland)
Group invariance and symmetries in control systems and mathematical physics
- 9.00 – 9.30 A.M. Bloch (University of Michigan)
Double bracket equations in optimization, control. and mechanics
- 9.30 – 10.00 P.S. Krishnaprasad (University of Maryland)
Patterns in control
- 10.00 – 10.30 Coffee break
- 10.30 – 11.00 J.E. Marsden (Caltech)
Stabilization of balance systems
- 11.00 – 11.30 E.D. Sontag (Rutgers University)
Stabilization under observation errors
- 11.30 – 12.00 H.J. Sussmann (Rutgers University)
Geometry and optimal control
- 12.30 – 13.30 Lunch

Session 5: Lecture Hall A

Chairperson: C.I. Byrnes (Washington University)

- 13.30 – 13.55 B.R. Barmish (University of Wisconsin)
Probabilistic design for quadratic stabilizability as a convex program
- 13.55 – 14.20 G.S. Chirikjian (Johns Hopkins University)
Closed-form solutions of the heat equation on $SO(3)$: applications of rotational diffusion and averaging
- 14.20 – 14.55 T.E. Duncan (University of Kansas)
Fractional Brownian motion
- 14.55 – 15.20 T. Taylor (Arizona State University)
Stochastic matrices: geometry, control and asymptotics
- 15.20 – 15.35 Tea break
- 15.35 – 16.00 R. Tempo (Politecnico di Torino)
Probabilistic robustness analysis of uncertain control systems
- 16.00 – 16.25 A.S. Willsky (MIT)
Why the world can't do without more estimation theory
- 16.25 – 16.50 W.S. Wong (Chinese University of Hong Kong)
Estimation and control problems with finite communication bandwidth constraints
- 16.50 – 17.15 Y. Yamamoto (Kyoto University)
Sampled-data systems: the past and the future
- 17.15 – 17.40 V.A. Yatsenko (National Space Agency of Ukraine)
Parameter estimation of almost periodic signal via controllable bilinear observations

Session 6: Lecture Hall D

Chairperson: (P.E. Crouch, Arizona State University)

- 13.30 – 13.55 A. Astolfi (Imperial College)
Control of the Brockett integrator: an ever challenging problem
- 13.55 – 14.20 R. Hirschorn (Queen's University)
Control of nonlinear systems with friction
- 14.20 – 14.55 H. Kimura (Tokyo University)
Uniqueness of Representation of Model Set
- 14.55 – 15.20 S. Lloyd (MIT)
Nonholonomic feedback control of quantum systems
- 15.20 – 15.35 Tea break
- 15.35 – 16.00 J. Loncaric (NASA LaRC)
Sensor/actuator placement via optimal distributed feedback
- 16.00 – 16.25 S. Nikitin (Arizona State University)
Nonlinear control synthesis and Brockett's view of isoperimetric problems
- 16.25 – 16.50 V. Polotski (Ecole Polytechnique)
Time-varying state feedback and output injection
- 16.50 – 17.15 D. Seto (Carnegie Mellon University)
On dynamic reconfiguration of real-time control systems
- 19.00 Dinner at the Harvard Faculty Club
Prof. S.K. Mitter (MIT) will give an after-dinner Laudatio.

List of registered participants (October 15, 1998):

D. Aeyels (University of Gent)
S.K. Agrawal (University of Delaware)
A. Astolfi (Imperial College)
K.J. Astrom (Lund Institute of Technology)
D. Atroune (University of Georgia)
R. Baheti (National Science Foundation)
J. Baillieul (Boston University)
W. Baker (McKinsey & Company)
J.D. Baras (University of Maryland)
B.R. Barmish (University of Wisconsin)
D.J. Bell (UMIST)
A.M. Bloch (University of Michigan)
E. Bristol (The Foxboro Co.)

L. Bushnell (Army Research Office)
C.I. Byrnes (Washington University)
R. Canales (IIE, Mexico)
J. Chandra (US Army Research Laboratory)
G.S. Chirikjian (Johns Hopkins University)
M. Chyba (Harvard University)
J.J. Clark (McGill University)
D. Cochran (Arizona State University)
S. Coraluppi (Alphatech)
P.E. Crouch (Arizona State University)
L. Dai (Washington University)
J. Dehaene (University of Leuven)
D.P. Dobkin (Princeton University)
T.E. Duncan (University of Kansas)
L. Faybusovich (University of Notre Dame)
N.J. Ferrier (University of Wisconsin)
M. Fu (University of Maryland)
P.A. Fuhrmann (Ben Gurion University)
K. Furuta (Tokyo Institute of Technology)
J. Hammer (University of Florida)
B. Hanzon (Free University Amsterdam)
U. Helmke (University of Würzburg)
R. Hirschorn (Queen's University)
Y.-C. Ho (Harvard University)
D. Hristu (Harvard University)
J.F. JaJa (University of Maryland)
T. Kailath (Stanford University)
N. Kajena (Harvard University)
K. Keeler
H. Kimura (University of Tokyo)
J. Kosowsky (Harvard University)
G. Kovatch (U.S. Department of Transportation)
O.P. Kreidl (Alphatech)
A.J. Krener (University of California)
M. Krichman (Rutgers University)
P.S. Krishnaprasad (University of Maryland)
F. Lamnabhi-Lagarigue (Laboratoire des Signaux et Systèmes, Supelec)
F. Silva Leite (University of Coimbra)
N.E. Leonard (Princeton University)
W.S. Levine (University of Maryland)
D. Liberzon (Yale University)
S. Lloyd (MIT)

J. Loncaric (NASA LaRC)
S. Marcus (University of Maryland)
J.E. Marsden (Caltech)
C.F. Martin (Texas Tech)
S.K. Mitter (MIT)
F. Monroy-Perez (Universidad Autonoma-Metropolitana)
D. Montana (BBN)
K. Morgansen (Harvard University)
A.S. Morse (Yale University)
N. Munro (UMIST)
R.M. Murray (United Technologies)
S. Nikitin (Arizona State University)
B. Pasik-Duncan (University of Kansas)
V. Polotski (Ecole Polytechnique)
M. Pukmel
M. Rabi (Harvard University)
N. Rao (SCT Corp.)
S. Sastry (University of California)
D. Seto (Carnegie Mellon University)
M.A. Shayman (University of Maryland)
S.T. Smith (Lincoln Labs)
E.D. Sontag (Rutgers University)
P.P. Sotiriadis (Harvard University)
V. Sundarapandian (Washington University)
H.J. Sussmann (Rutgers University)
A. Tannenbaum (University of Minnesota)
T. Taylor (Arizona State University)
R. Tempo (Politecnico di Torino)
J. Tsitsiklis (MIT)
N. Twum-Danso
Y. Wang (Florida Atlantic University)
J.C. Willems (University of Groningen)
D. Williamson (Australian National University Canberra)
A.S. Willsky (MIT)
W.S. Wong (Chinese University of Hong Kong)
Y. Yamamoto (Kyoto University)
V.A. Yatsenko (National Space Agency of Ukraine)

**Appendix:
Letter of Invitation**

August 14, 1998

Professor P.E. Crouch
Dean College of Engineering and Applied Sciences
P.O. Box 875506
Arizona State University
Tempe, AZ 85287-5506

Dear Peter,

It is a pleasure to share some good news regarding the forthcoming October Conference we are holding in honor of Roger W. Brockett's 60 birthday. With recently awarded financial support from the Army Research Office, the organizers have sufficient funds to cover reasonable costs associated with your travel. I am thus able to offer you up to \$1,000.00 in travel expense reimbursement. Because of U.S. Government restrictions on the use of these funds, you will be required to use a U.S. flag carrier for any international travel. The detailed terms and conditions of our grant include the following:

Travel supported by U.S. government funds under this grant shall use U.S. flag air carriers for international air transportation of people and property to the extent that such service is available in accordance with the International Air Transportation Fair Competitive Practices Act of 1974 and the interpretative guidelines issued by the Comptroller General of the United States in the March 31, 1981 amendment to Comptroller General Decision B138942.

It is also important to note that the funds we provide will be given as reimbursements, and thus hotel and meal receipts as well as airline ticket stubs will be required.

Let me take this opportunity to remind you that it is a good idea to make your hotel reservations at this time if you have not already done so. (The block of hotel rooms will only be held until the middle of September, and rooms in the Boston area are very difficult to find during the month of October.) Hotel information is available on our Web site: <http://eng.bu.edu/Brockettfest>.

Jan and I are very much looking forward to seeing you at this festive occasion honoring the life's work (to date) of Roger W. Brockett.

Sincerely,

John Baillieul
(on behalf of Jan Willems)

PS: The program for 'Brockettfest' will be available soon on our Web site <http://eng.bu.edu/Brockettfest>. Please note that the Friday morning kickoff sessions will take place at Boston University, Room 206, Photonics Center, 8 St. Mary's Street. All other sessions, including those of Friday afternoon, will take place in the Science Center at Harvard University.